What is the Role of Air Pollution Modeling in Policy Making?

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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

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The air pollution is a growing problem in a number of cities around the world. Over the years, starting from the days of the infamous London smog[1] and Los Angeles smog[2] episodes, the cities around the world have established programs to better understand the air pollution sources and facilitated ways to control the pollution. The growing industrialization, transportation, and demand for energy in all forms, is multiplying the air pollution related health impacts and environmental damages, not only in the big cities, but also in the growing number of secondary cities.

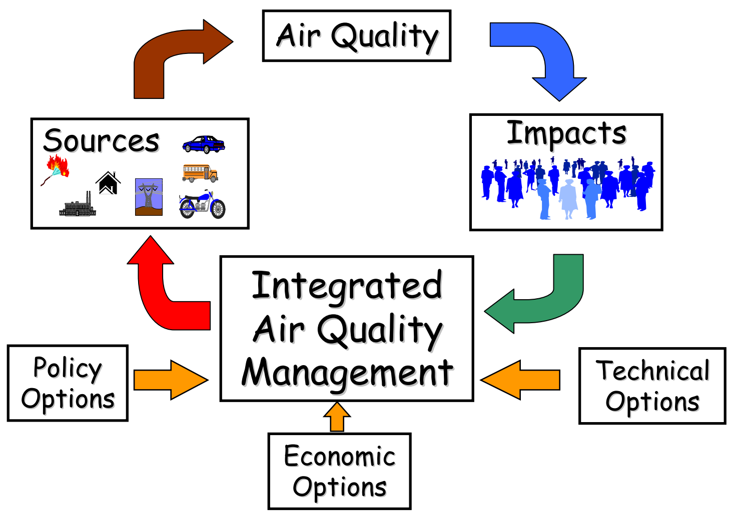

Figure 1: Integrated air quality modeling for policy support

The cities are also learning from past experiences. For example, the acid rain problems in Europe during the industrial revolution led to the analytical frameworks to support sulfur legislations and technology advancements to control acid rain producing pollutants, such as sulfur dioxide and nitrogen oxides[3]. Following a successful implementation of the acid rain control program in Europe and United States, the experience led to the establishment of RAINS-Asia program to address similar problems in the Asian countries. A perfect example of lessons learnt and transferred is the "two control zone" program in China to control SO_2 pollution is the cities and acid rain in the effected regions[4]. These programs were successful in part due to the modeling efforts.

While the RAINS program (renamed and expanded as GAINS to include the greenhouse gas emissions and pollution analysis) is one example, over the decades a number modeling exercises were conducted in conjunction with monitoring (on ground, in the air, and from

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[1] The great smog of 1952 in London, England @ http://en.wikipedia.org/wiki/Great_Smog_of_1952
"Cleaning up London's dirty air", Economist, October 8th, 2009
@ http://www.economist.com/world/britain/displaystory.cfm?story_id=14587625
[2] Smogtown: The Lung-Burning History of Pollution in Los Angeles by Chip Jacobs and William Kelly
@ http://www.amazon.com/Smogtown-Chip-Jacobs/dp/1585678600
[3] RAINS-Europe developed by IIASA, Austria @ http://gains.iiasa.ac.at/index.php/home-page
Acid Rain program by US EPA @ http://www.epa.gov/acidrain/
[4] "China: Air Pollution and Acid Rain Control – The case of Shijiazhuang and the Changsha Triangle Area" ESMAP report # ESM267-03, The World Bank, USA @ http://go.worldbank.org/R22KKMM0N0
"Historical Analysis of SO2 Pollution Control Policies in China" by C. Gao et al., January 2009, Environmental Management @ http://www.springerlink.com/content/c71pq2777l832325/

the satellites) across the world. These modeling activities include bottom-up methodologies using consumption levels and top-down methodologies using the monitoring data[5]. For example, MEGAPOLI[6] (*Megacities: emissions, urban, regional and global atmospheric pollution and climate effects, and integrated tools for assessment and mitigation*) campaign is being carried out as part of the EUR 3.4 million EU-funding under the Environment (including climate change) Theme of the Seventh Framework Programme (FP7). MEGAPOLI is coordinated by the Danish Meteorological Institute and involves 22 partners from 12 European countries. The program also includes some Asian cities in the following phases.

The idea of visually modeling air quality and the tools to support policy making and regulations is well established by the scientific and academic communities across the world. However, not many decision makers and planners understand why this is important. For example, why modeling is important and useful to analyze the impacts of policy measures; why modeling is important to study the pollution sources; or how the modeling can be conducted utilizing the resources available. Sometimes the planners understand the rationale for modeling tools, but they must convince decision makers, who ultimately must give authority for implementation of interventions. This document delves on the need to answer why, what, when, and how the air pollution modeling supports the policy making.

1. Why Use Models for Policy Analysis?

In the world of sustainable development, the planners wonder why air pollution modeling is important at all. After all, the monitoring of the ambient pollution should speak for itself. In essence, the measurements are what to be modeled. *Why add an extra layer of abstraction*?

The reason is that there are a number of clear benefits that models provide a development organization. They are enhanced communication, better planning, reduced risk, and reduced costs.

Take the growing number of cities across the world – we have the megacities with at least 10 million inhabitants and the secondary cities following the megacities in many ways other than development. While the cities are growing and experiencing the air pollution problems first, they are also on the fore front of implementing newer policies and emerging technologies. Whatever the national legislation may be, the cities are the first to react and lead the way in promoting innovative technologies and standards across multiple sectors.

The question "**which policy will be introduced**" is political and very likely a decision considered in dialogue with multiple stakeholders. But, the decision on "**when to introduce**" the policies and regulations and "**what is the potential**" air pollution reduction can only be answered via a series of modeling efforts. The modeling exercise also enables the involved agencies optimize the environmental and social benefits of an array of policy

[5] For details on the two methods and examples, refer to the SIM-air working paper No. 16 "SIM 16-2009: Urban Particulate Pollution Source Apportionment: Part 1 - Definition, Methodology, and Resources" @ http://urbanemissions.info/simair/simseries.html
[6] MEGAPOLI @ http://web.dmi.dk/pub/megapoli/maininfo/projsum.html

measures available to the stakeholders. The underlying theme is *Timing is everything* to maximize these benefits under the "**what-if**" scenarios (**Figure 2**), which is vital for the decision making and is only achieved through modeling.

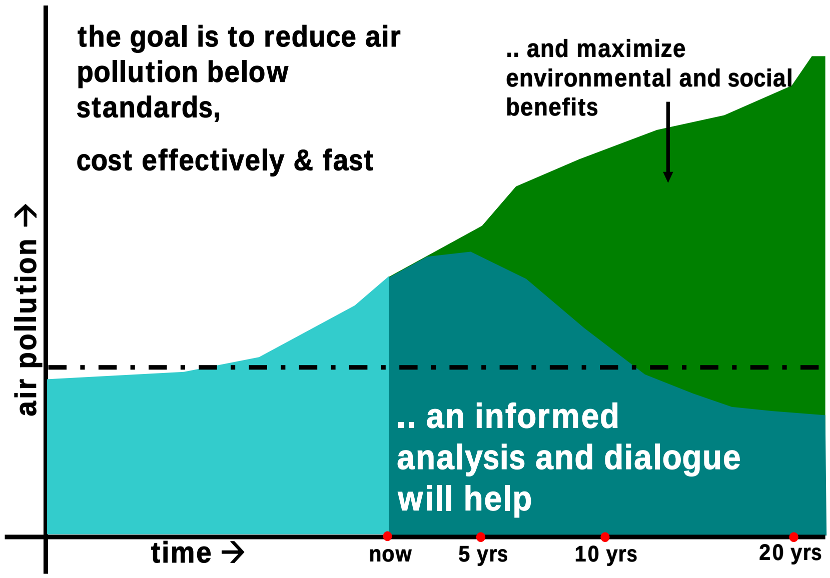

Figure 2: Timing is everything to maximize the benefits of various control interventions

At urban and regional level, where the air pollution impacts are felt the most and using models for emissions and pollution analysis is necessary. The integrated air quality modeling (**Figure 1**) provides a platform to better understand the emission sources, the spatial and temporal variations in pollutant concentrations, the possible impacts of the pollutants on ecology and people, and provide a baseline to estimate the "what if" scenarios to optimize the environmental and social benefits in the future (**Figure 2**).

There are a number of steps are involved in putting together an operational modeling system for a city or region and advantages of a coordinated modeling effort are also plenty. For example, for a regulatory body, monitoring of air pollution is crucial and conducted routinely for most of the criteria pollutants. In this regards, an integrated air pollution modeling exercise can **provide necessary information on the local hot spots** and identify key areas for monitoring.

Within an area or place, exposure to air pollution typically varies with higher levels of exposure proximate to sources of pollution. The motor vehicle emissions result in higher exposure for those living near freeways and busy roadways. Significant sources of intra-urban variation in air pollution also include truck routes, bus yards and distribution centers, commercial and industrial exhaust, topology, and the aspect ratio of urban canyons. Regional monitoring data conducted for national and state air quality standards does not assess the spatial variation in air pollution within cities nor does it identify air pollution "hot spots". A facility complementing the air quality measurement and modeling tools to respond to the growing need to identify air quality hot spots within cities is very important.

Figure 3 presents the results from a 3D modeling of particulate pollution in London[7], highlighting the hot spots for exposure analysis and further monitoring.

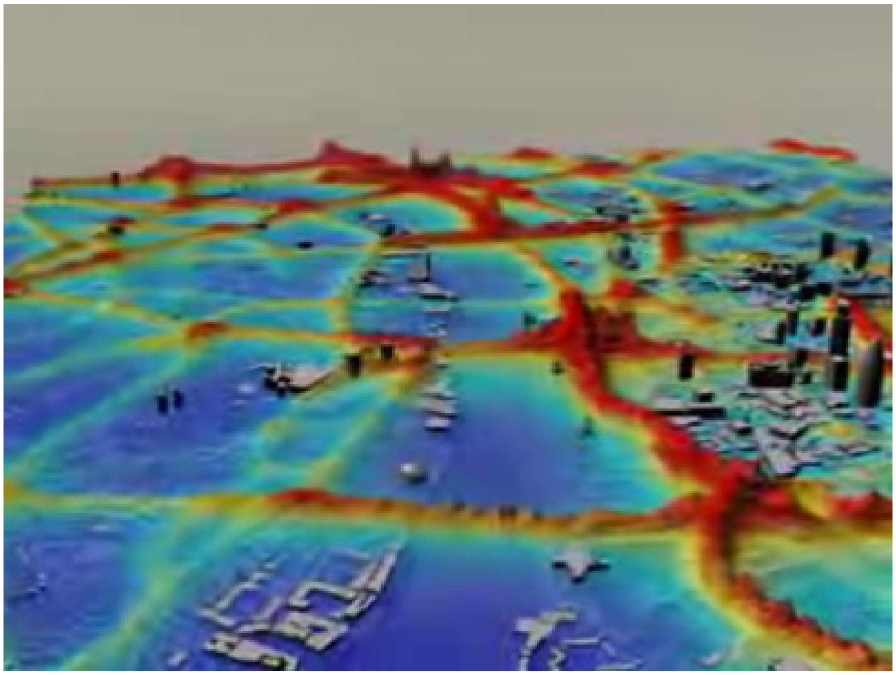

Figure 3: A 3D depiction of PM pollution in London

While the monitoring data from a location can provide only two-dimensional data – for the particular location and time – the modeling exercise over an area can provide four-dimensional data in space and time. Since this includes the use of multiple platforms – combining the ground based measurements, satellite retrievals, and chemical transport modeling, the depth of information is enormous.

The use of air pollution models for policy support is widely accepted and a number of tools exist to support this activity at multiple scales[8]. While the tools exist, it is important to note that the data requirements for any methodology are critical and the final results depend on the confidence levels of the input data.

[7] London pollution in 3D @ http://www.visualcomplexity.com/vc/project.cfm?id=513
[8] Modeling tools for air pollution analysis and management
@ http://urbanemissions.blogspot.com/2009/01/tools-for-air-pollution-analysis.html

Shanghai, China

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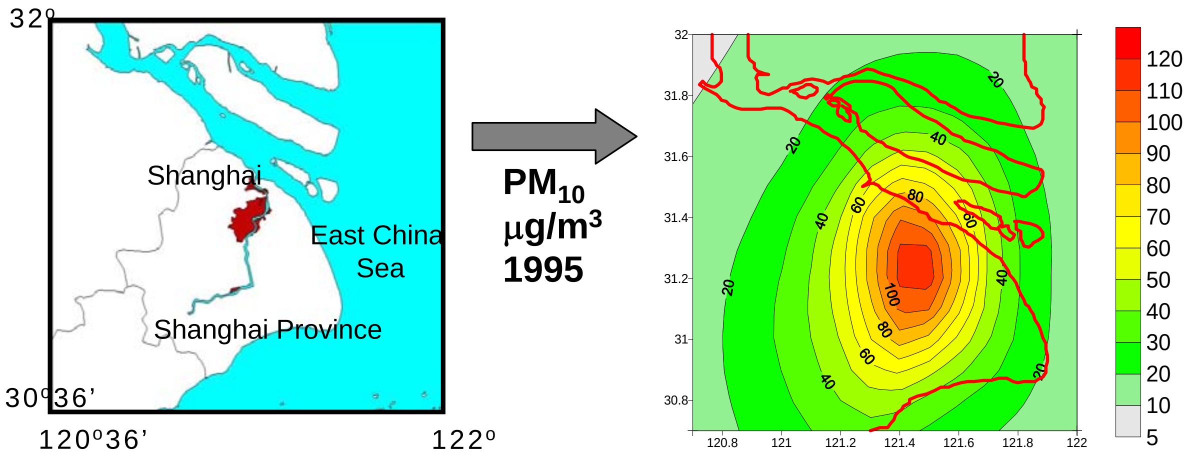

This study was conducted in 2001-02 with 1995 as the base year and estimates extend to 2020 for **cost-benefit analysis** under business as usual and two control scenarios for particulates, sulfur dioxide, and nitrogen oxides. Base year emissions were estimated at 166 ktons of PM_{10}, 68 ktons of $PM_{2.5}$, 285 ktons of NO_x and 458 ktons of SO_2 in 1995. Control options included application of IGCC technology for the power plants and substitution of coal with gas along with relocation for the industrial sector.

Emissions inventory development and dispersion modeling was conducted using SIM-air framework & ATMoS model; followed by benefits analysis for health and cost benefit analysis for the options. Results are summarized below and are published in *J. of Environmental Management, 2004.*

Health Benefits (US $ mil)		Power Scenario	Industrial Scenario
Mortality	Low	139	88
	Medium	347	221
	High	1,030	656
Morbidity	Low	38	24
	Medium	57	36
	High	119	76
Work Day Lossess		13	8
Total Benefits		190 – 1,162	121 – 741
(Median Case)		**(417)**	**(266)**
Scenario Cost (US$ mil)		**395**	**94**

An example of "what if" modeling exercise

2. How Does the World See the Progress in Air Quality Parameters?

The indicator for progress and development is linked to public health. In turn public health is linked to the air quality in the cities, among many other parameters – such as water and sanitation, food and nutrition, and smoking[9]. The urban air pollution along with the indoor air pollution (especially in the rural areas) is the growing concern for premature mortality[10]. The World Health Organization estimates ~2 million deaths annually due to outdoor air pollution[11] (ENS, 2006) and combined with climate change an additional ~315,000 deaths annually[12] (Reuters, 2009).

Among the Millennium Development Goals, No. 7 reads "*Ensure Environment Sustainability*" and the target for this goal is to "*integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources*"[13]. Although the air quality is not listed as one of the primary indicators, this is considered a derived indictor directly linked to the energy use[14].

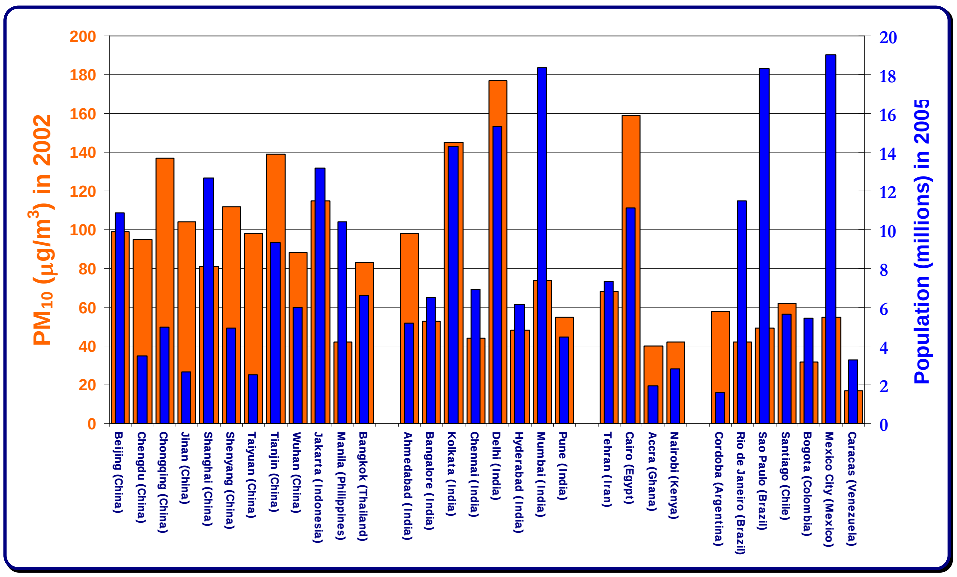

Figure 4: Population vs. PM_{10} in Asian urban centers (WDI, 2007)[15]

The air pollution is a direct consequence of the fossil fuel consumption and unlike the greenhouse gases; the air pollutants have immediate and chronic impacts on human health.

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[9] "Comparative Quantification of Health Risks" by WHO, 2004
@ http://www.who.int/healthinfo/global_burden_disease/cra/en/
[10] A summary of results from studies across the world on premature mortality due to air pollution
@ http://urbanemissions.info/mortality.html
[11] ENS, 2006 @ http://www.ens-newswire.com/ens/oct2006/2006-10-06-01.asp
[12] Reuters, 2009 @ http://www.reuters.com/article/environmentNews/idUSTRE54S29P20090529
[13] UN Millennium Project @ http://www.unmillenniumproject.org/
[14] Scientific America, 2009, "Linked Challenges: Climate Change and Energy Use"
@ http://www.scientificamerican.com/podcast/episode.cfm?id=linked-challenges-climate-change-an-09-09-24
[15] World Development Indicators - http://devdata.worldbank.org/data-query/

The local pollution is also known to induce long term ecological damage via acidification and eutrification[16]. Over the past twenty years and in the next twenty years, the megacities of the world are expected to expand and increase in number, putting more pressure on the need for better infrastructure, social circumstances, and environment (**Figure 4**). Under business as usual, in industrialized and developing countries, the air pollution from fossil fuel combustion is expected to have detrimental impacts on human health and the environment.

Some progress has been made in understanding the social and economic consequences of the air pollution[17]. In most of the cities, there is increased awareness for monitoring the air pollution, especially for the criteria pollutants such as particulates (PM), SO_2, NO_x, Carbon Monoxide (CO), and Ozone. However, for many reasons the monitoring is limited to few points in and around the city, which may or not be representative of the city size.

There is NO thumb rule on number of monitors that must be installed for a certain size of the city, but the costs involved (equipment, labor, and maintenance) prohibit the number of monitors that can be installed and maintained by a regulatory body. In this regards, also presented early, **the modeling efforts can help and supplement** the lack of enough monitoring sites across a city or a region.

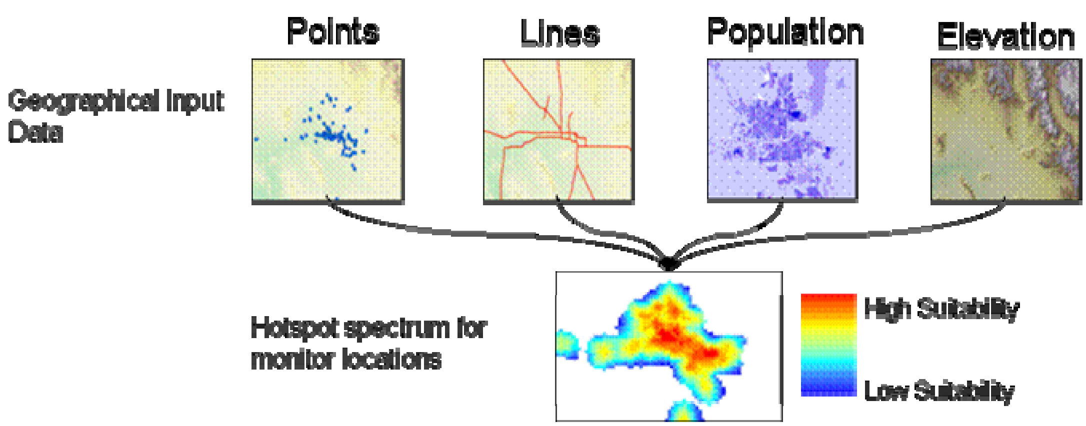

Figure 5: Monitor density and location analysis techniques[18]

[16] Acid Rain program by US EPA @ http://www.epa.gov/acidrain/
"Particulate Pollution Combined With Airborne Soot Adds To Global Warming", Science Daily, June 30th, 2009 @ http://www.sciencedaily.com/releases/2009/06/090629200808.htm
[17] "Public health impact of air pollution and implications for the energy system" (2001) @ http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.energy.25.1.601
WHO, 2005, "Comparative quantification of health risks" @ http://www.who.int/healthinfo/global_burden_disease/cra/en/index.html
"Regional atmospheric pollution and transboundary air quality management" (2005) @ http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.energy.30.050504.144138
"Multimodel estimates of intercontinental source-receptor relationships for ozone pollution" (2009) @ http://www.agu.org/pubs/crossref/2009/2008JD010816.shtml
"UN reports pollution threat in Asia" (2008) @ http://www.nytimes.com/2008/11/14/world/14cloud.html
[18] Prof. Gregory Carmichael, The University of Iowa

3. How to Utilize Air Quality Forecast Models for Policy Support?

A single most important policy support provided by an operational air quality forecasting system is public awareness. With the growing air pollution problems in most of the cities, the reduction of health risks is top priority and a forecast system (in conjunction with monitoring data) can provide the necessary support to avoid the exposure risks.

In general, the policy decisions (short term and long term) by the respective pollution control boards are based on the monitoring data. However, in some cases, the modeling efforts play a crucial role. For example, before and during the Olympic Games, the air quality in Beijing, China was at critical stages. A number of interventions were introduced 2 months prior to the games, such as restricting half of city's personal vehicles and shutting down a number of industries, not only in Beijing, but also in the neighboring cities[19]. While these decisions were partly in conjunction with the monitoring data, the "what if" scenario analysis and a real time forecasting system played a crucial role in designing these interventions. The industries in the neighboring cities were shutdown following a study to assess the transboundary air pollution (outside of Beijing)[20].

The regulatory bodies have the responsibility of making the necessary and adequate decisions for better air quality and these bodies are always in need for better data - data not only to support the decisions, but also to inform the public and media of the current situation and progress in the future.

Figure 6: Air pollution forecasting systems in USA and Canada (www.airnow.gov) and UK (www.airquality.co.uk)

The air quality forecasting systems, already established and operational in United States, Canada, and Europe (**Figure 6, Table 1**), provides a vehicle to not only inform the public about the risks of possible air pollution exposures, but also use the assimilated data for policy analysis of the future scenarios.

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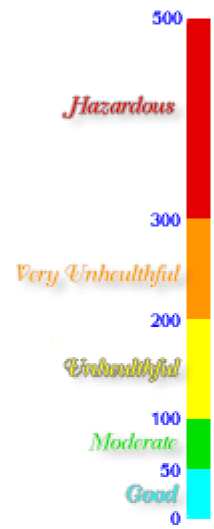
[19] Science Daily, "Olympic Pollution Controls In Beijing, China, Had Big Impact On Air Pollution Levels", December 19th, 2008, @ http://www.sciencedaily.com/releases/2008/12/081216131016.htm

[20] A summary of the air pollution reductions efforts is provided by the Clean Air Initiative for Asian Cities @ http://www.cleanairnet.org/caiasia/1412/article-72720.html

Typically, the pollution is presented as an air quality index (AQI), while the absolute numbers are used for further analysis. The AQI is an "index" determined by calculating the degree of pollution in the city or at the monitoring point and includes five main pollutants - particulate matter, ground-level ozone, sulfur dioxide, carbon monoxide, and nitrogen dioxide. Each of these pollutants has an air quality standard which is used to calculate the overall AQI for the city. Simultaneously, one can also establish the limiting pollutant(s), resulting in estimating the AQI.

In numbers, AQI is represented between 0 to 500 with 0 representing good air and 500 representing hazardous air. For better understanding and presentation, the AQI is broken down into six categories, each color coded with the number scale.



- Good is 0-50 and means satisfactory air quality
- Moderate is 51-100 and is for acceptable air quality
- Unhealthy for Sensitive Groups (tan) is 101-150 and means sensitive individuals with sensitive skin may be affected
- Unhealthy is 151-200 and almost everyone may experience problems
- Very unhealthy is 200-300 and is a health alert, where everyone may have health problems
- Hazardous over 300 numbers may contribute to emergency health problems and will affect most people

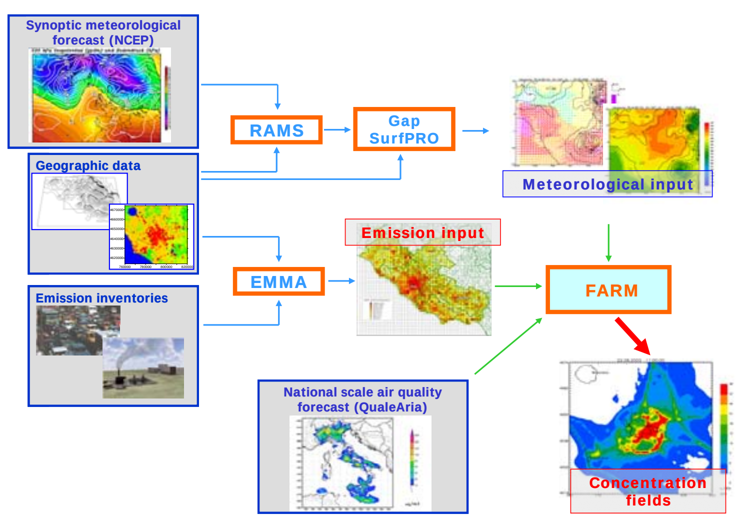


Figure 7: Architecture of air quality forecast system in Rome, Italy

Establishing the AQI in a forecast mode is not an easy exercise, as it involves modeling of emissions, dispersion of the pollutants depending on local meteorology and terrain, and presentation of the results (**Figure 7**). However, a number of platforms (and groups) are established and in use, for the readers to choose and learn (and apply)[21].

Table 1: Examples of AQI reporting across the world

City, Country	*Website*
United States & Canada	http://www.airnow.gov
Canada	http://www.airhealth.ca/
Mexico City, Mexico	http://www.sma.df.gob.mx/simat2/ingles.php
Baja California, Mexico	http://aire.bajacalifornia.gob.mx/eng/index.cfm
Europe	http://www.eea.europa.eu/maps/ozone/map
France	http://www.prevair.org/en/index.php
Paris, France	http://www.airparif.asso.fr/pages/prevision/previs
Marseille, France	http://www.atmopaca.org/
Alsace Loraine, Germany	http://w3.atmo-alsace.net/progs/navigation/frameset_main.php
London, UK	http://www.londonair.org.uk/london/asp/default.asp
Central London, UK	http://www.airtext.info/
Austria	http://www.umweltbundesamt.at/umweltschutz/luft/luftguete_aktuell/tgl_bericht/
Belgium	http://deus.irceline.be/%7Ecelinair/pm/pm10.php?lan=en#anim
Cyprus	http://www.airquality.dli.mlsi.gov.cy/Default.aspx?language=854584c2-5fce-4878-a561-0d250ab3a1c9&pageid=37
Norway	http://www.luftkvalitet.info/
Netherlands	http://www.lml.rivm.nl/data/smog/index.html
Germany	http://www.env-it.de/umweltbundesamt/luftdaten/map.fwd;jsessionid=6544D11FEBFC20A1DAD3DA7F4EBE7307?comp=PM1
Switzerland	http://www.bafu.admin.ch/luft/luftbelastung/aktuell/index.html?lang=en
Sao Paulo, Brazil	http://www.cetesb.sp.gov.br/Ar/mapa_qualidade/mapa_qualidade_rmsp.asp
Santiago, Chile	http://www.conama.cl/rm/568/channel.html
Beijing, China	http://www.beijingairquality.cn/index.php?f=new
China	http://www.vecc-mep.org.cn/eng/
Hong Kong	http://www.epd-asg.gov.hk/eindex.php
South Korea	http://eng.airkorea.or.kr/
Malaysia	http://www.doe.gov.my/
Thailand	http://www.pcd.go.th/AirQuality/Bangkok/Default.cfm
Colombo, Sri Lanka	http://www.airmacsl.org/
Taiwan	http://210.69.101.141/taqm/en/default.aspx
Ho Chi Minh City	http://www2.nilu.no/airquality/hcmc/index.cfm
Singapore City	http://app.nea.gov.sg/psi/
Abu Dhabi, Saudi Arabia	http://www.adairquality.ae/en/home/overview.aspx?type=0&topic=1&id=ab787351-c611-4c03-8c17-cfe964dfebbb
New South Wales, Australia	http://www.environment.nsw.gov.au/AQMS/aqidaily.htm
Victoria, Australia	http://www.epa.vic.gov.au/air/bulletins/

[21] A workshop on "Air Quality Forecasting Systems" in collaboration with World Meteorological Organization and Indian Institute of Tropical Meteorology, India was conducted in December 2008. Details @ http://www.tropmet.res.in/~gurme/

The dissemination of the AQI results have evolved with technology and there are innovative ways to present the information to the public and the media. For example, via balloons in Paris[22], via websites (**Table 1**), via google earth in Milan, via photo journals in Beijing[23], via digital exhibition in Madrid[24], and via lasers in Helsinki[25].

4. What are the Common Misconceptions in Policy Making via Modeling?

Modeling and forecasting is entirely based on monitoring data: This is FALSE. The modeling is a bottom-up exercise following a series of steps, starting with emission inventory development not only for the area of interest, but also covering external areas to support boundary conditions and transboundary impacts, dispersion of the emissions through a chemical transport model using the assimilated meteorological conditions for the area, and exposure assessment and scenario analysis. During this process, the monitoring data, in many forms and from multiple sources (as much as possible) is used to calibrate and validate the methodologies applied. However, the monitoring data itself is not used directly to model or forecast the air quality for a particular area.

Air pollution modeling and data intensive: This is TRUE. However, many resources have been developed and numerous groups are utilizing the models at multiple scales to better understand the local, regional, and global air pollution. Depending on the data availability, the models can be used for (a) evaluating the what-if scenarios (b) validating the emissions inventories (c) studying the missing sources of air pollution (d) better understanding the chemical mechanisms and physical transformations in an area and (e) support policy decisions with examples.

Air pollution modeling should be conducted using complex models: This is FALSE. In the absence of a developed modeling system, useful information can be generated from first level, back-of-the-envelope, and inexpensive analysis. That is, a city or an area can begin their modeling exercise with off-the-shelf inputs and locally available models. From this base, an iterative process of repeated model improvement can be applied to develop more sophisticated emission inventories and include region-specific information. The iterative process of improving the models is based on analyzing the inconsistencies that result from each round of bottom-up and top-down analyses (monitoring). This eventually leads to a high quality evaluation system where the top-down and bottom-up analyses approach converge. However, the process cannot stop here. Measurements should continue and models need to change as the pollution characteristics of the region being managed changes. That is, the management system needs to reflect the changing economic activity of the urban area.

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[22] AQI via balloons in Paris @ http://urbanemissions.blogspot.com/2008/07/using-ballons-to-visualize-air.html
[23] Photo journals of air pollution in Beijing @ http://urbanemissions.blogspot.com/2009/01/photo-diary-of-air-pollution-in-beijing.html
[24] Digital exhibition of air pollution in Madrid @ http://intheair.es/index.html
[25] Illuminating air pollution using lasers in Helsinki @ http://urbanemissions.blogspot.com/2009/01/public-awareness-art-for-illuminating.html

In Conclusion

Policymakers in rapidly growing urban areas increasingly recognize that addressing air quality issues is an urgent priority. The developing countries should aspire to imitate the air pollution modeling systems (**Table 1**), irrespective of the modeling limitations. Studies and dialogues should include properly identifying the sources of pollution to formulate rational and effective policies and make informed investment decisions related to air quality improvements.

The air pollution modeling components are inter-correlated and must be studied through an interdisciplinary research program that combines all aspects of air pollution including its scientific, societal, economic, and political issues and that integrates field, laboratory, modeling, and policy analysis on multiple air pollutants at multiple scales.

Our goals should be

- To develop and improve integrated air quality modeling system that can simulate the sources, evolution and human/environmental impacts of air pollutants at all scales (urban, regional, and global)
- To enhance scientific understanding of air pollution and provide valuable information for the development of optimal emission control strategies
- To provide educational opportunities to solve the most urgent environmental problems
- To promote interactions and collaborations among industry, governmental, and academia to study air quality and its interactions.

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